Tribology: Friction, Lubrication, and Wear

Course Syllabus
MECH 560
Spring 2021

Professor: Prof. Gagan Srivastava (secondary instructor: Prof. C. Fred Higgs III)
Email: gs37@rice.edu higgs@rice.edu

Class Time: M, W 6:30PM - 7:50PM (MEB 128)

Office Hrs: Friday 2:00 – 3:00 PM (remotely). Other options scheduled as needed.

Text: *Engineering Tribology*, Williams, J.A., Cambridge University Press, 2005. ISBN#: 0521609887 (Available in online stores, e.g., https://www.amazon.com/Engineering-Tribology-John-Williams/dp/0521609887)

Homework: Problem sets will be assigned mostly on a weekly basis, but sometimes less. The problem sets will be collected at the beginning of class. Additionally, there will be two exams, and a final project which will be presented orally in front of your peers.
Late work loses 10% each day it's late. Once solutions are circulated, no late HW will be accepted.

Grading Weight:

Problem Sets:	40%
Exam 1:	20%
Exam 2:	20%
Final Project:	20%

Grading Scale: 100—A—85—B—73—C—60—D—45—F

Objectives:

1. To introduce students to the fundamentals of friction, lubrication and wear of surfaces
2. To expose students to fundamental tribological issues involved in well-known mechanical engineering applications such as bearings, hydrodynamic fluid film bearings, gas bearings, and rolling element bearings
3. To expose students to novel and advanced applications of tribology in: data storage systems, oil-free bearings, IC processing, nano-manufacturing, biomedical engineering, MEMS lubrication, and multiphase flow tribology
4. To give students working experience in the computational aspects of tribology such as surface generation, contact mechanics, and hydrodynamic lubrication
5. To have a working understanding of the seminal research papers in tribology and their derivatives, through lively class discussions, homework assignments and final projects
6. To enable students to make a seamless transition from this course to conducting research or working in the field of tribology

Lectures:

The entire class will meet twice a week for 1 hr and 20 minutes. The lectures will be supplemented by course notes in MS PowerPoint (student and annotated post-lecture formats), which will often be provided at the beginning of class but often downloaded after class in the annotated form. These will be in the "Course Documents" section of Canvas.

Cheating (short statement):

Cheating and plagiarism is unethical behavior that is not tolerated in this course or at Rice University. Students with questions about the definition of cheating or plagiarism are referred to the Rice Undergraduate Student Handbook. URL: (http://honor.rice.edu/honor-system-handbook/)

- *Exams***:** Cheating on exams is not tolerated and will be dealt with following the policies in the Rice Student Handbook.

- *Homework Assignments***:** You are encouraged to discuss and work together with other students on the homework assignments. However, each student must write up his or her own solutions. Copying of assignments is not allowed.

Video/Audio recording or Photographing:

No student may record, photograph, or tape any classroom activity without the express written consent of Prof. Higgs. If a student believes that he/she is disabled and needs to record or tape classroom activities, the student should contact the Rice University Disability Support Services to request appropriate accommodation. In the event that such an accommodation has been arranged, the material may not be further copied, distributed, published, or otherwise used for any other purpose without the express written consent of Prof. Higgs. Failure to adhere to this rule could result in sanctions from Rice.

Rice Exam Policies:

The conduct of examinations can be found here: http://honor.rice.edu/files/2010/11/Conduct-of-Examinations-Rev.-Feb-2013-u8ilft.pdf

The Rice Code
Source: see http://honor.rice.edu/files/2010/11/Academic-Fraud-and-the-Honor-System-wwh52d.pdf

ACADEMIC FRAUD AND THE HONOR SYSTEM
Academic fraud is one of the areas of university life that fall within the scope of the Honor System. Violating the Honor Code requirements of an assignment or failing to credit one's sources constitutes academic fraud and would, therefore, violate the Honor Code.

It is the responsibility of each student to complete all assignments according to the requirements set forth by the professor. All assignments submitted at the University are pledged, either explicitly or implicitly, and students fulfill their responsibilities to their fellow students under the Honor System when they can pledge, in good conscience, that their work is their own.

Cultures differ in their views about the ownership of ideas. In some cultures people believe that ideas, like air and sunshine, cannot be owned, and they do not acknowledge those who first publish ideas. Some countries are only now developing laws for ownership of patents and copyrights. Rice University is not part of such traditions: it follows Western conventions for dealing with intellectual properties. Its Code of Conduct acknowledges the unique intellectual contributions of individuals at the same time it recognizes that all individuals rely on the concepts, creations, and inventions of others. Although some students come from countries and cultures that do not recognize individual contributions to knowledge, Rice University expects these students and all other students and faculty to participate in an academic community that honors the intellectual work of others and acknowledges their influences. This community's commitment is formally recorded in a system of rules called The Honor Code. This booklet explains how these rules apply to the use of other people's ideas and works in student papers and presentations.

Rice decided to prepare this booklet after examining an exemplary handbook written for students at the University of Virginia. We gratefully acknowledge the University of Virginia's generosity in allowing us to imitate the organization and content of their student guide, Academic Fraud and the Honor System. Additional content assistance was also drawn from Wesleyan University's The Blue Book. A Definition of Academic Fraud.

On all academic written work done by students at Rice University, the following pledge is either required or implied:
"On my honor, I have neither given nor received any unauthorized aid on this (examination, quiz or paper)." This statement is regarded as an indication that the student understands and has complied with the requirements of the assignment as set forth by the professor. Any violation of the pledge that occurs outside of a testing situation is considered academic fraud. There are several types of academic fraud, and they are as follows:

I. Plagiarism
Plagiarism is defined by the Honor Council as: "quoting, paraphrasing, or otherwise using another's words or ideas as one's own without properly crediting the source." All specifically designated written assignments are conducted under the Honor System. In preparing written work, research and the utilization of another person's words or ideas is in many cases essential. The Honor Council assumes that, unless otherwise credited, all work submitted by the student is intended to be considered as his or her own work. Any time a student draws particularly or generally from another's work, the source should be properly credited. What is meant by proper crediting is left to the discretion of the professor. A professor, when assigning a paper, should make known to the students what is expected in the researching and referencing of the paper. However, it is the student's responsibility to find out from each professor how work for that professor should be credited. Neglect of proper citation shall be considered academic fraud.

II. Multiple Submission
Multiple submission is the resubmission of any work by a student that has been used in identical or similar form in fulfillment of any academic requirement at this or another institution. Under certain conditions a student may be permitted to rewrite an earlier work or to satisfy two academic requirements by producing a single piece of work, more extensive than that which would satisfy either requirement on its own. In such cases, however, the student must secure prior permission from each instructor involved. If the student has revised an earlier essay, the earlier essay should be submitted with the final version. If a single extended essay has been written for more than one course, the fact must be clearly indicated at the beginning of the essay. Thus, submitting the same work for credit in more than one class, either concurrently or consecutively, without prior permission from the professor shall be considered academic fraud.

III. False Citation
A false citation is any attribution to, or citation of, a source from which the referenced material was not in fact obtained, including use of a quoted reference from a non-original source while implying reference to the original source. This shall be considered academic fraud.

IV. False Data
False data are data that have been altered or contrived in such a way as to be deliberately misleading. The submission of such data shall be considered academic fraud. *This policy applies, in all respects, to this course.*

(Syllabus subject to revision at the discretion of the instructor)

Topic Covered
Lecture 1: *Preview of Tribology 2021: It's still Physics!*
I.) Characterizing a surface • What is a surface? • Surface topography (i.e., statistical, fractal, deterministic) • Techniques of surface examination • Computational analysis and generations of surface topography (statistical, fractal) • Surface Metrology Lab tour (later in semester; after construction)
II.) Contact Mechanics • Surface and Subsurface Stresses • Hertzian contact • Contact of rough surfaces [Programming assignment: Greenwood-Williamson, Winkler foundation, deterministic (voxels), and fractal contact] • Rolling element bearings
III.) Friction: Solid-solid-contact • Thermal contact mechanics • Flash temperature
IV.) Wear • Adhesive wear • Abrasive wear • Corrosive wear • Delamination wear • Third-body and wear particle tribology • Particle Flow & Tribology Lab (PFTL) tour
Tribo-Test 1
V.) Hydrostatic Bearing Analysis VI.) Hydrodynamic Lubrication • Derivation of the Reynolds Equation • Solutions to the Reynolds Equation—1D Plane slider bearing • Solutions to the Reynolds Equation—1D Rayleigh Step bearing • Pivot pad and tilting bearing • Hard disk drive (HDD) lubrication—gas lubrication
More Hydrodynamic Lubrication Journal Bearing Theory : • Journal bearing solutions for long bearing • Journal bearing solutions for short bearing
Numerical Hydrodynamic Lubrication • Crash course on programming in Mathematica® • Finite difference methods

	• Numerical solutions of 1D Reynolds Equation • Numerical solution of the squeeze film problem • Application of the Reynolds BC
VII.)	Elastohydrodynamic Lubrication (EHL) Mixed-Lubrication: Integration of Fluid and Contact Mechanics
	Tribo-Test 2
VIII.)	Special topics in Tribology: • Oil-free bearings (Foil, powder, magnetic, etc.) • Tribology in Nanomanufacturing (i.e., Chemical mechanical polishing) • Biotribology • Micro-tribology: MEMS • Particle flow tribology
IX.)	Special topics in Nanotribology • Nanotribology: why does macro-Tribology began to fail at nanoscales? • Nanoindentation • Adhesion • Tribo-applications where nanotribology becomes relevant (e.g., Magnetic hard drives, MEMs/NEMs)
	Final Projects: Presentation and Written Papers

FYI: The pace could be accelerated or decelerated at the professor's discretion.